UNIVERSITY OF DELAWARE
CENTER FOR COMPOSITE MATERIALS
INTERNATIONALLY RECOGNIZED EXCELLENCE

SMARTMolding UPDATE

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Outline

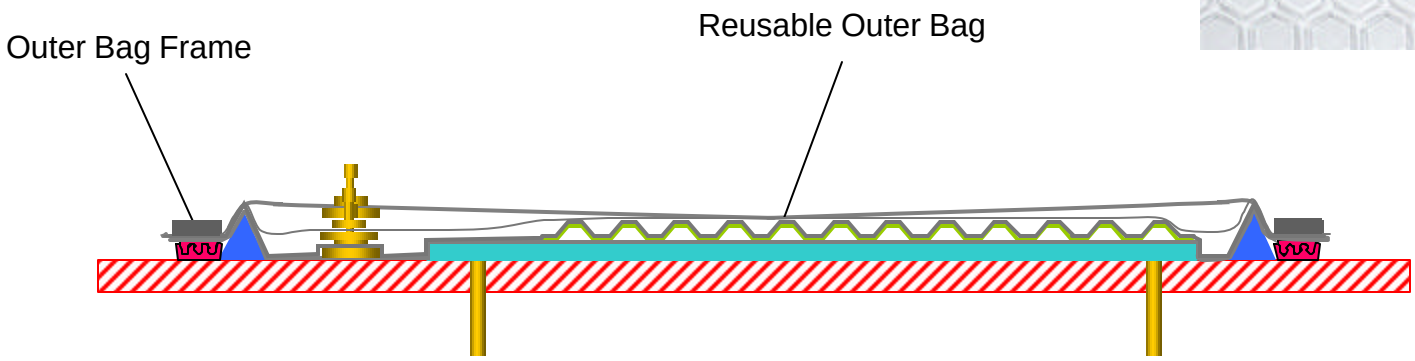
- **Review of new VARTM process variations**
  - **Channel-Assisted Resin Transfer Molding (CARTM)**
  - **Interlaminar Flow Media**
    - Verdant Polybeam™
- **New Features of SMARTMolding Software Suite**
  - **Design Tool**
    - Incorporated commercially available Distribution Media into Database
  - **Intelligent Process Control System**
    - Added Intranet connectivity
    - Automated Vacuum Debulking
    - On-line Work Instructions
    - Virtual Checklist of all Processing Steps
    - Sensor Test
  - **New Data Review Graphical User Interface**
    - Allows on-line reporting on all recorded data over Intranet
    - Export to Excel, Printing Capability

Outline

- **New Features of SMARTMolding Software Suite**
  - **Recipe Definition GUI (In Progress)**
    - Complete Process Flow Description (Recipe) is automated
    - Checks on Database and Process Consistency
  - **Automated Statistical Analysis Tool (In Progress)**
    - Detects Outliers
    - Ranking of Important Process Variables
- **New Features of SMARTMolding Hardware Suite**
  - **Wireless Tool-Mounted Sensors (In Progress)**
  - **Tool-Mounted Time-Domain Reflectometry**
- **Technology Transfer**
  - **Important Conference Participation**
    - SMARTMolding Demonstration at SAMPE '03 Long Beach, CA
    - Invited Lecture "Intelligent Process Control For Automated VARTM Processing" Composite Fabricator Association (CFA) Liquid Molding Conference in Dayton, OH
  - **In Progress of Updating Beta-Sites with new Software Components**
    - NSWC Caderock has been updated
  - **Strong Interest in SMARTMolding from several Companies**
    - Boating
    - Wind Energy

The CARTM Process I

- Channel-Assisted Resin Transfer Molding Process
- Patented and Commercially Licensed
- Similar attributes compared to FASTRAC, but flow media and completed double bagging systems are commercially available



Courtesy of

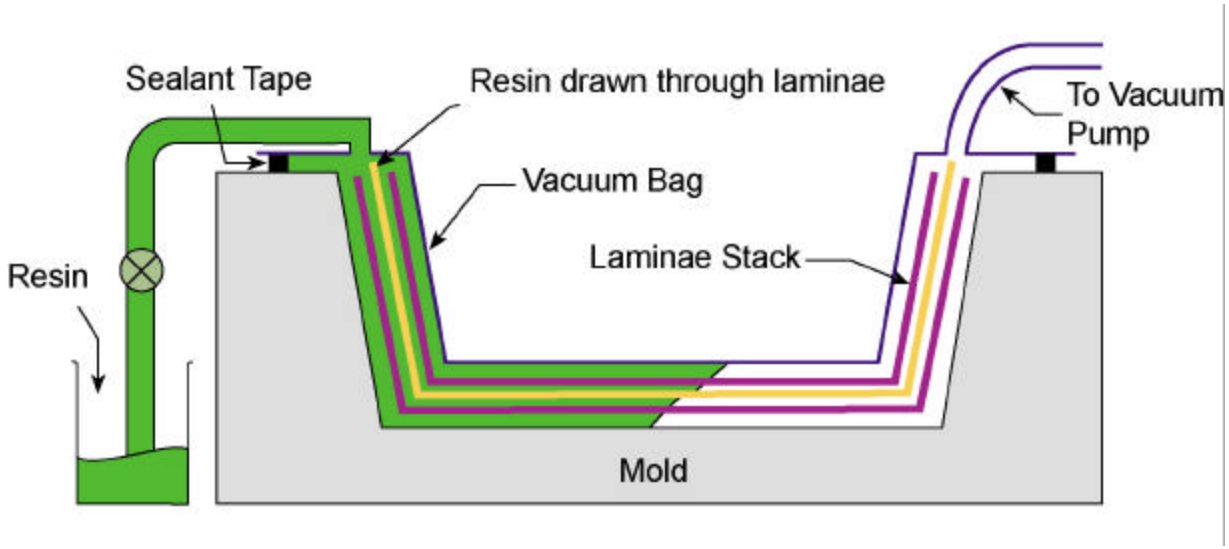
The CARTM Process II

- System can be modeled as a typical VARTM process with distribution media
  - Permeability is a function of CARTM media (channel pattern) and differential vacuum pressure
  - Opportunity to optimize surface flow for complex structures by designing the CARTM layer (off-line control)
  - On-line flow control possible by adjusting differential vacuum pressure
    - Zones
    - Vacuum gradient
    - Delay Lines

- Establishment of a CARTM workcell at UD-CCM in July with help of “Why not Composites”

Interlaminar Flow Medium

- Resin introduced through the preform via an integrated inter-laminar distribution media
- Peel ply not necessary
- Thick preforms can be divided in multiple laminates

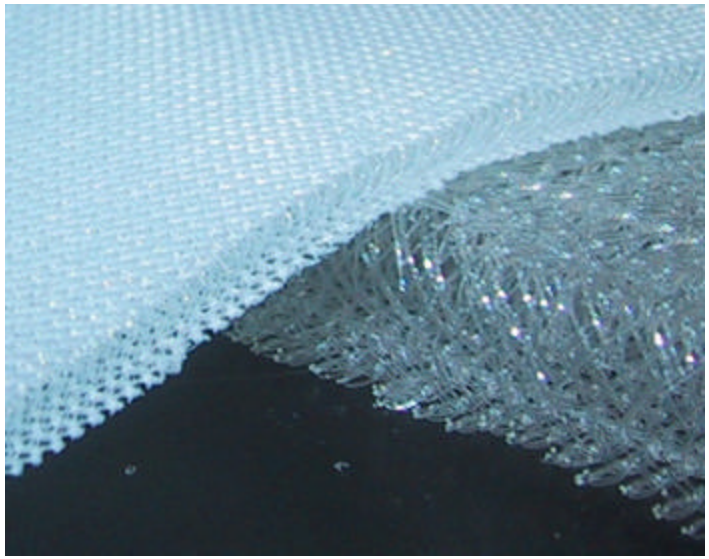


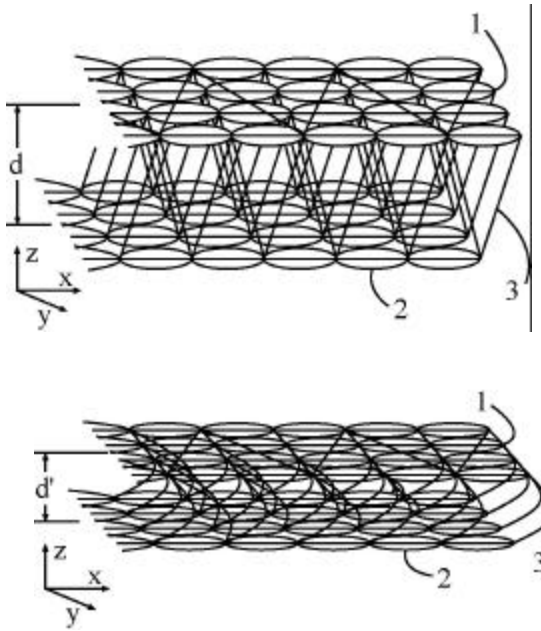
Courtesy of

Verdant Technologies
Composite Technology Solutions for the Environmental Age

Polybeam Flow Media™

- Patented Polybeam technology increases permeability during infusion due to spring-back and reduces porosity after infusion due to unique compaction behavior



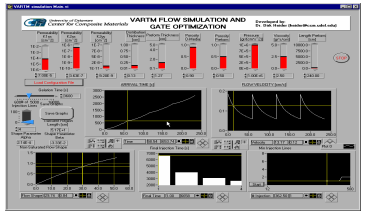


- Talks initiated with Verdant to evaluate compaction behavior and mechanical performance
  - Bonding to cored structure
  - Inter--laminar shear

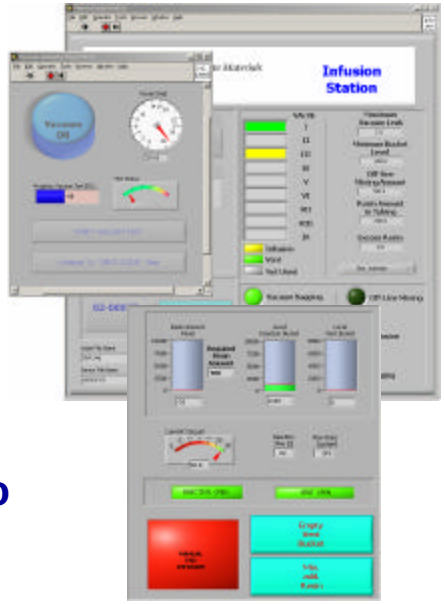
Courtesy of Verdant Technologies
Composite Technology Solutions for the Environmental Age

SMARTMolding Software Suite

Design Tool

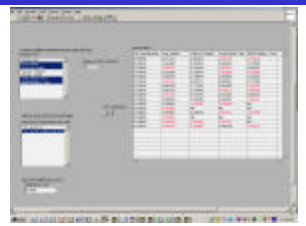


IPC System

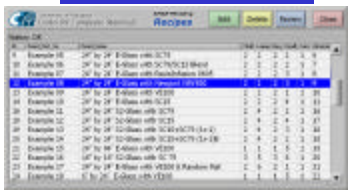


Data Review

Statistical Package



Recipe GUI

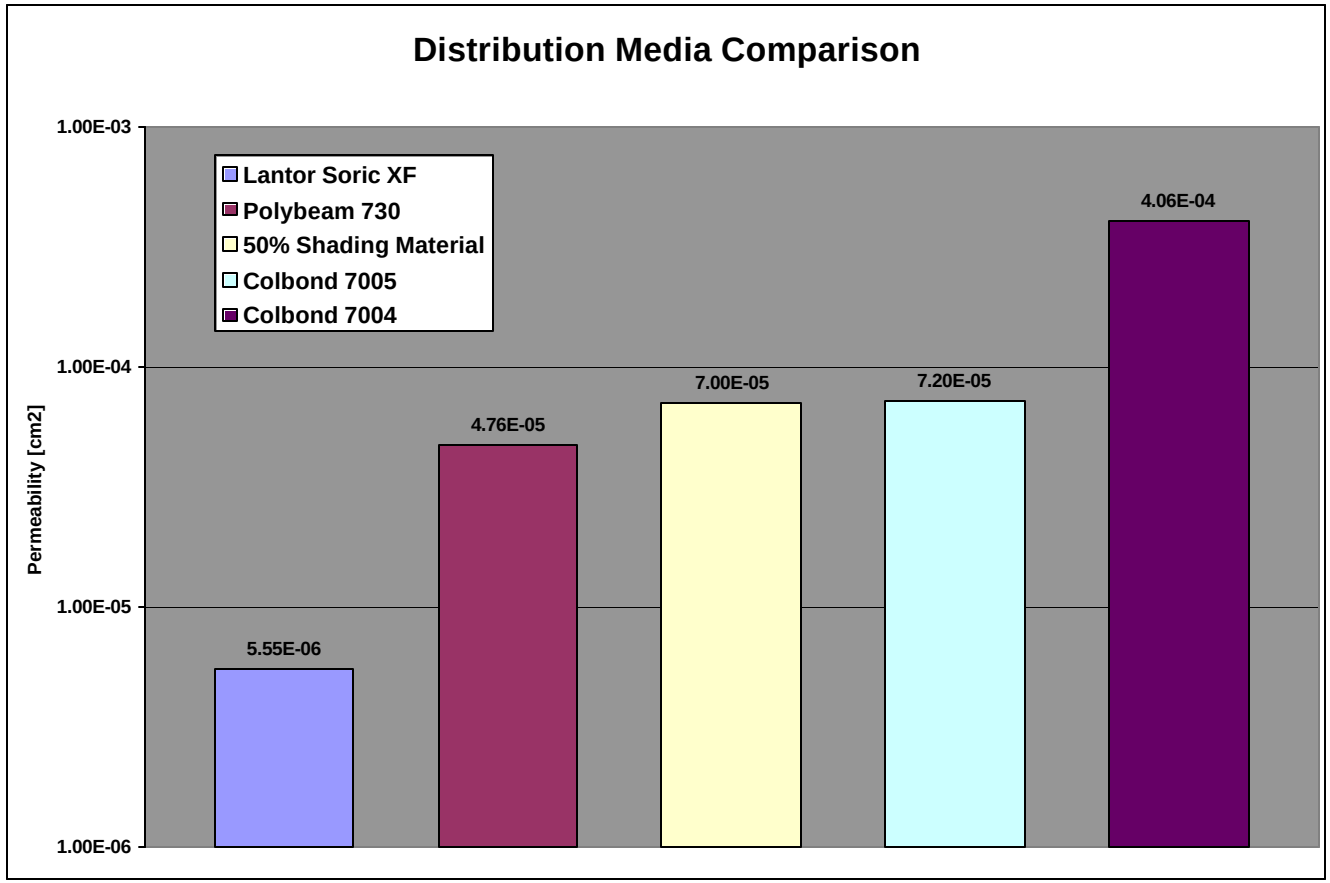


- Simple Interface, Limited to simple geometries
- Predicts Flow Times, Lead Length
- Optimizes # of Seq. Injection Lines
- Database with Material Properties

- Automates the VARTM Process
- Records the processing steps
- Reporting of collected data
- Enables statistical analysis
- Guidance Software to define process recipe

Added Permeability Data to Database of Commercially Available Distribution Media

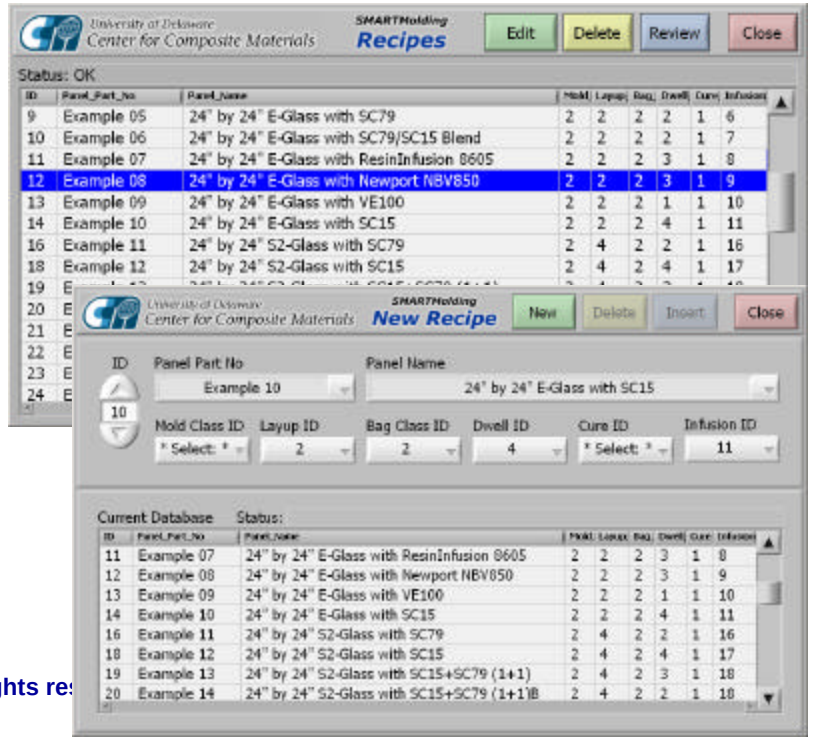
Data Courtesy of Gaetan Denis



- Database includes now 5 Distribution Media (4 more in progress)
- Design tool chooses DM based on lead length and flow times

Recipe Definition GUI

- **Supports Definition of**
  - **Process Set Points**
    - Vacuum Leak Level
    - Resin Volume
    - Debulking
      - Cycles
      - Vacuum Level and Cycle Time
    - Infusion Setup
      - Sensors
      - Valves
      - Sequential Injection Script
    - Dwell Time and Dwell Vacuum level
  - **Material Selection**
    - Materials and Material Sequence during Lay-up
    - Resin
    - Bagging
    - Mold
- **Validates complete definition of recipe**
- **Review Recipe Definition**

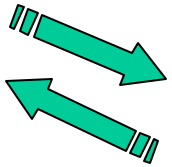


New IPC Graphical User Interface Features 1/2

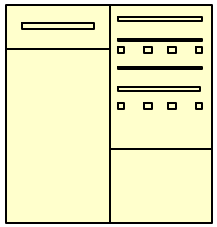
Intranet connectivity

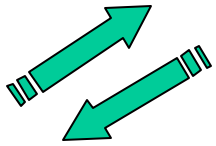
IPC 1

IPC 2



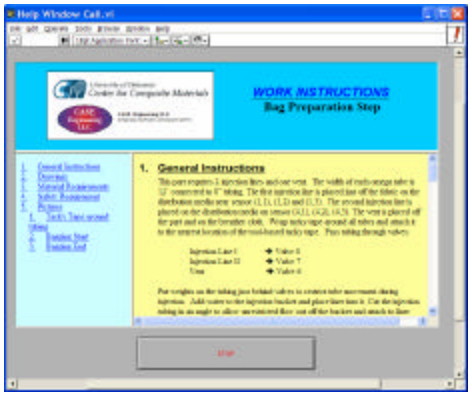
Server





- Automatic Backups
- Multiple IPC's can be connected

On-Line Work Instructions

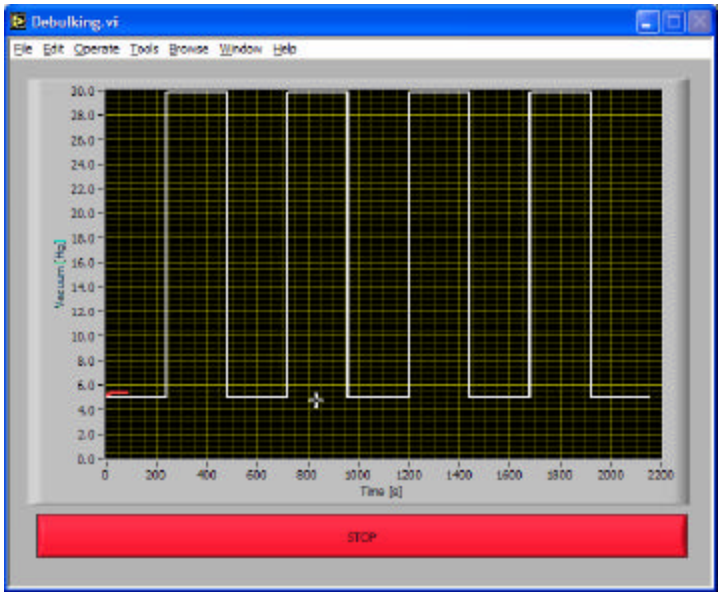


- MSDS
- Pictures
- AutoCAD drawings
- Video

Virtual Checklist of all Processing Steps

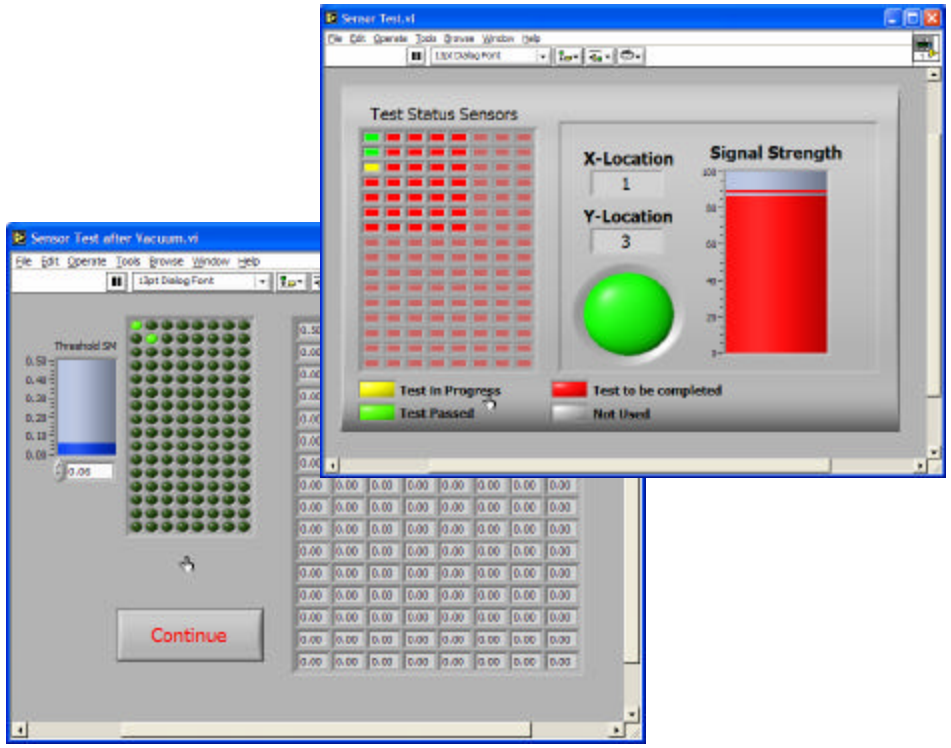
New IPC Graphical User Interface Features 2/2

Automated Vacuum Debulking



- Automatic Debulking
- Improves repeatability and reduces preform thickness prior to infusion

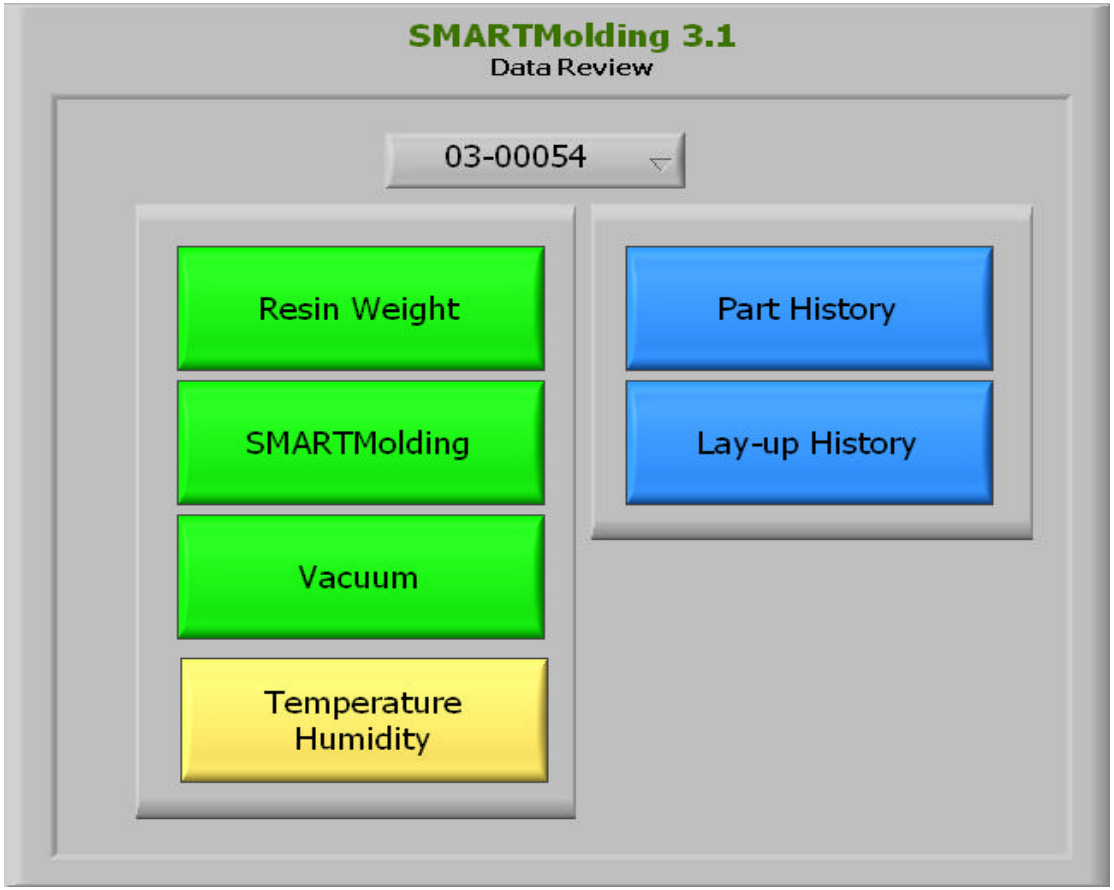
Sensor Test GUI



- Ensures sensor functionality
- Adjust resin arrival threshold for different resin systems

Data Review Graphical User Interface

DEMONSTRATION



Repeatability Analyses of the VARTM Process

- PhD student is establishing theoretical and experimental understanding of VARTM repeatability ➔ see presentation of Amoroux
- Boeing Corporation is supporting the VARTM repeatability project
  - Information will be provided from the AST Wing and CAI program
  - POC Boeing: Scott Holmes
    V-22 Affordability
    Integrated Defense Systems, PHL

Statistical Analysis Package

Objective

- Flag outliers based on process parameter values and reduce number of post-inspections
- Rank parameters based on their repeatability
- Identify parameters that relate to quality of part
- Detect quality based on parameter values

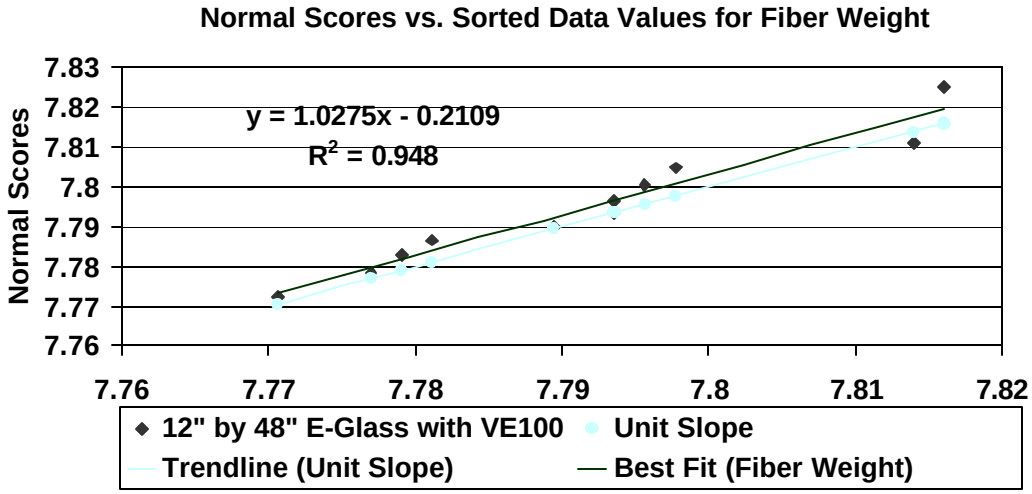
Approach

- Iterative statistical detection scheme for outliers
- Repeatability measure to rank parameters,

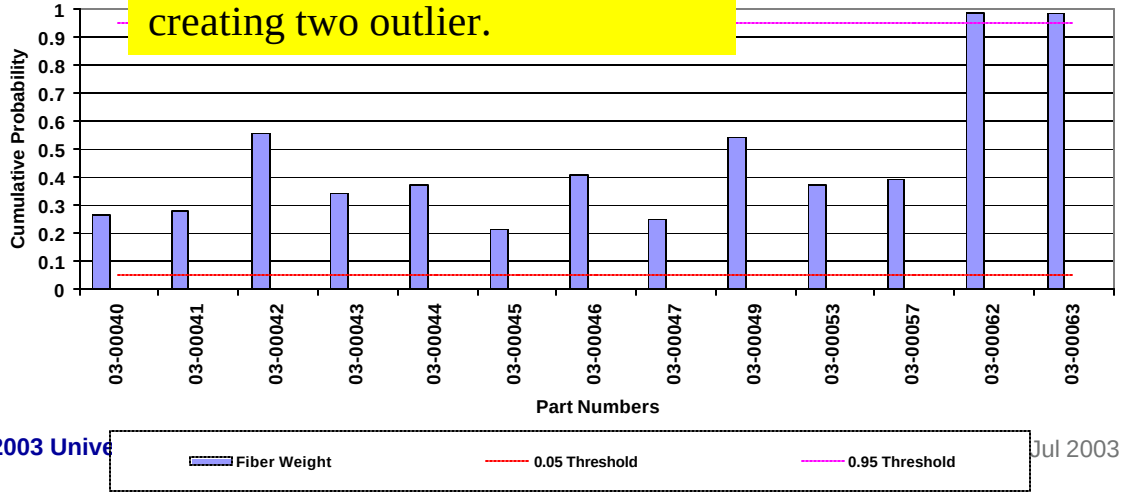
Data Analysis: Fiber Weight

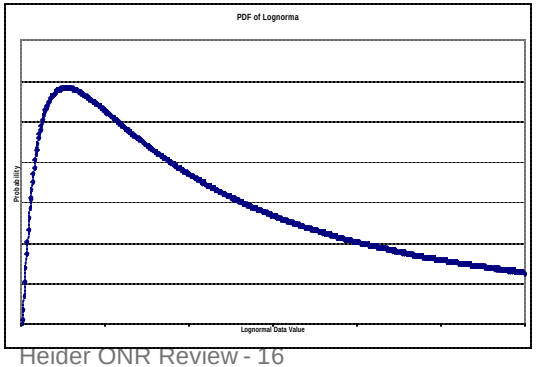
- Discrete vs. Continuous
  - Discrete parameters have one value per part, Ex. Fiber Weight
  - Continuous parameters are time-dependent, Ex. Resin Weight Infused vs. Time
- Lognormal Distribution
  - Assuming Lognormal distribution for process parameters (When RV X is lognormally distributed, then ln(X) is normally distribted.)
- Lognormal Validation
- Outlier Detection based on Probability Level

Lognormal Distribution fits the Fiber Weight Data



Additional Layer was added to part 03-00062 and 03-00063 creating two outlier.





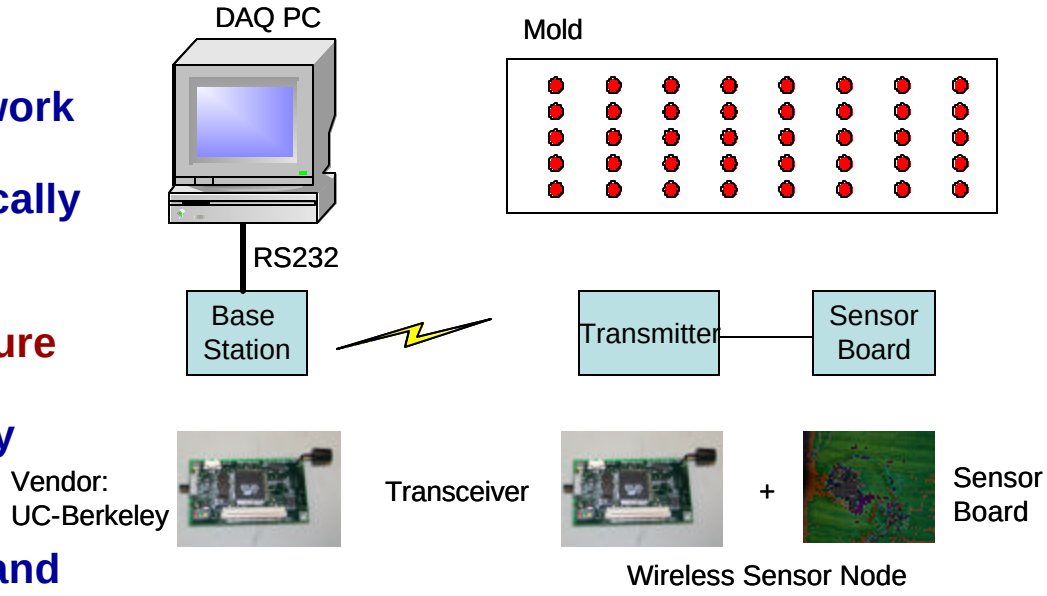
Wireless Sensor Network

Objective:

- Reduce noise due to wiring
- Allow seamless switching of molds without connecting/disconnecting sensor cables

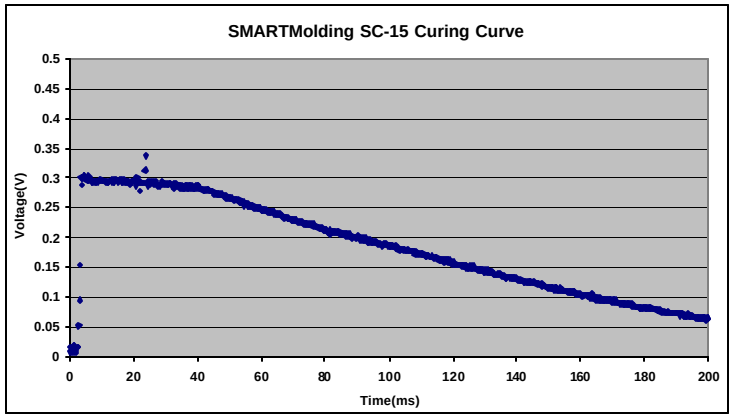
Approach:

- Using existing wireless sensor network technology
- Develop custom DAQ to connect locally to transmitter
  - DC-based flow measurement
  - Other sensors such as temperature and humidity sensor
- Wireless sensor network technology replaces multiplexing technology
- Sensor signal quality is improved due to a reduction in cross-talking and cable noise
- Simple plug & play reduces the setup time. System can be reduced if mold is scrapped



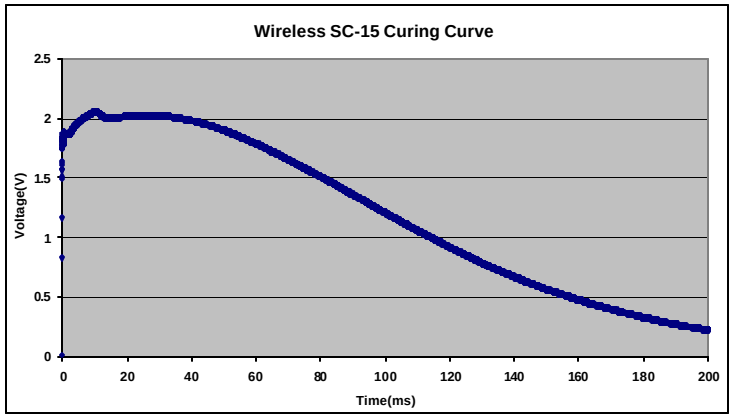
Improved Signal to Noise Ratio 5:1

Existing SMARTMolding System

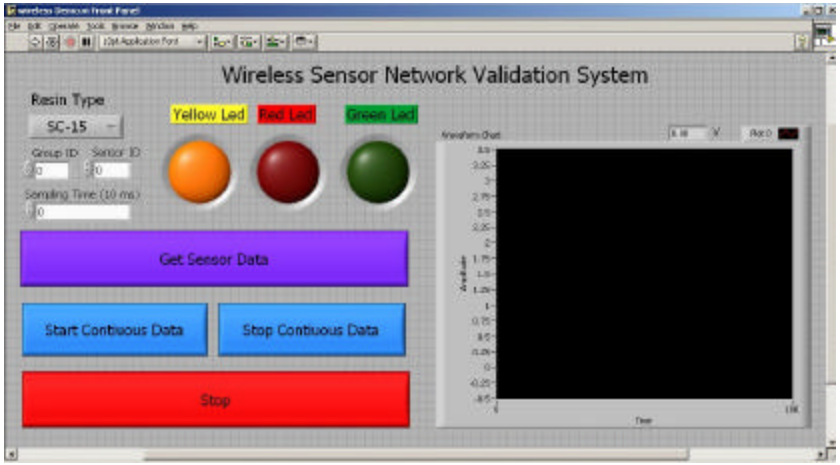


SNR=10*log(0.3/0.01)=4.7db

Wireless Single Sensor



SNR=10*log(2.02/0.01)=23.05 db

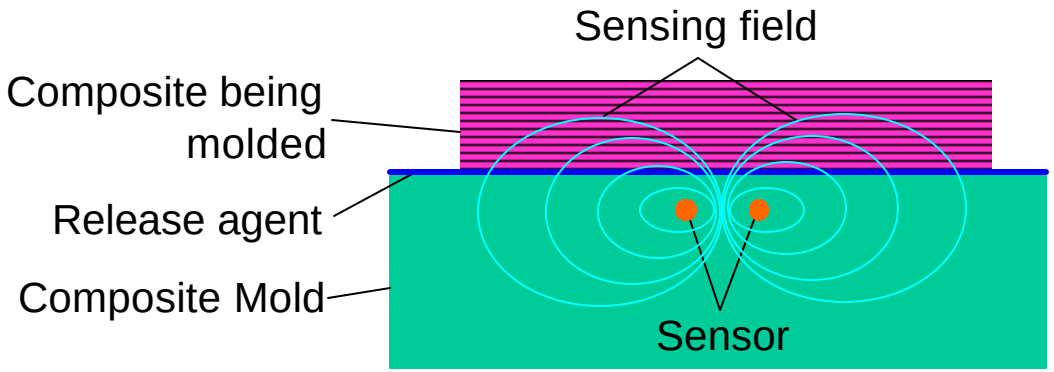


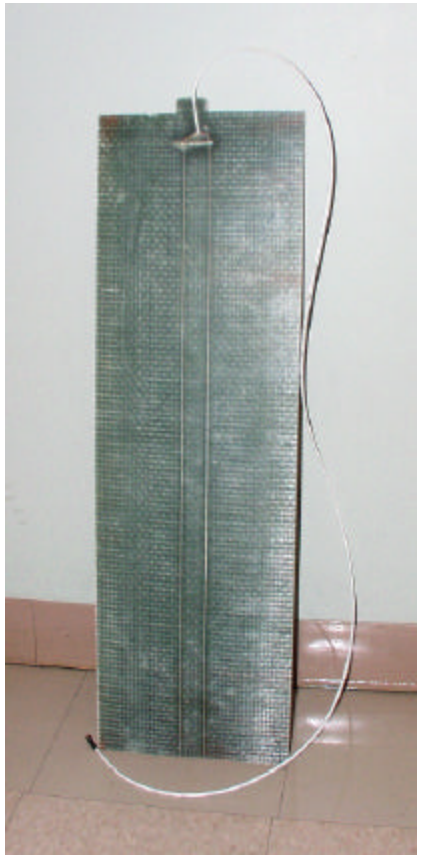
Demonstration!!!

Tool-Embedded TDR Sensing

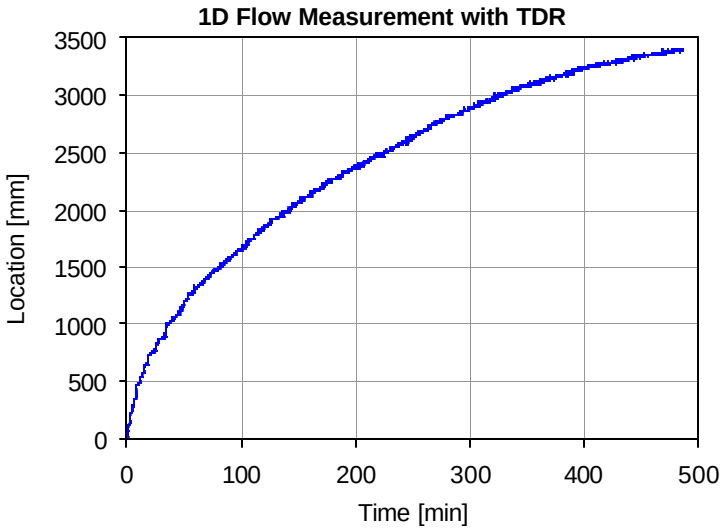
Technology benefits:

- ✓ Non-contact sensing;
- ✓ Sensing through release agent and gel coat;
- ✓ No post service required;
- ✓ Low cost manufacturing;
- ✓ Application for non-conductive polymer based tools with various curvatures.





5m Tall Structure Infusion

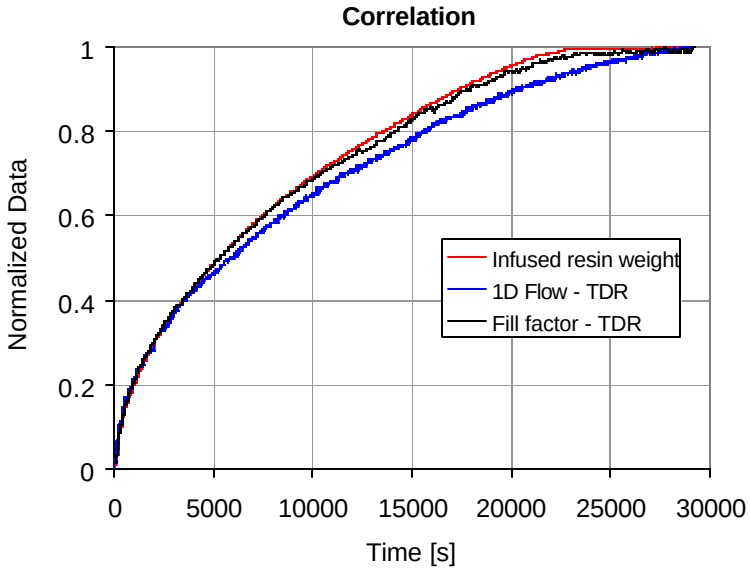


✓ Tool embedded TDR sensing has been tested during vertical infusion;

✓ TDR sensor response fits infused resin weight data very well.

✓ 1D TDR Flow data shows flow progression after fill factor shows no response

✓ The resin cures in bucket faster and stops injection in the preform



Summary

- New VARTM processes create opportunity for on-line control
- Additions to IPC software creates new capabilities (debulking) and adds to industrial requirements (work instructions, intranet capable)
- Major advances have been implemented to create user-friendly SMARTMolding environment
  - Recipe Definition
  - Data Review
- Data mining software components have been implemented to review automatically large amount of data collected and to detect processing outliers
- New sensor hardware shows promise for industrial environment
  - Reduced wire count
  - Tool-Mounted TDR allows monitoring through gel coat